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ANALYSIS AND DESIGN OF AN AEROMEDICAL EVACUATION LITTER STANCHION

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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This report describes and documents an aeromedical evacuation litter stanchion design and analysis. The MSC/NASTRAN general purpose finite element computer code is used for the analysis. Also, details of 10 identical stanchion pairs actually built under the effort are given. The stanchion pairs are yet to be subjected to structural tests at various G-levels and in appropriate directions. The final design is a 3-litters-on-one-side arrangement with support for the structure using seat tracks common to Civil Reserve Air Fleet (CRAF) aircraft. Higher density litter arrangements such as 4-on-a-side or back-to-back 3 or 4 litter stanchions are explored. Floor loads exceed those generally available for these cases.

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TABLE OF CONTENTS

LIST OF FIGURES

QUALITY INSPECTED 1

A-1

LIST OF TABLES

ANALYSIS AND DESIGN OF AN AEROMEDICAL EVACUATION LITTER STANCHION

BACKGROUND AND INTRODUCTION

This research project developed as a follow-up from the earlier study (1) which evaluated the use of the long range international (LRI) portion of the Civil Reserve Air Fleet (CRAF) which could be used for large scale air evacuation of casualties. These casualties could occur in natural disasters, from an act of war, or from some national or international emergency situation.

The Texas A&M study (1) tried to define a broad range of requirements to be met when using CRAF. One of the items which was included in this earlier study was a preliminary design for litter stanchions to be mounted in the CRAF floor seat tracks common to all CRAF aircraft. A very preliminary analysis of the structural integrity of the litter stanchion design was made to evaluate its feasibility for use in CRAF (1). No analysis, however, was conducted to determine the loads delivered to the aircraft floor. The structural integrity is critical when considering the use of CRAF because of the generally lower load-carrying capability of the floors in CRAF compared to the floors in military transport aircraft. Also, the requirement that these aircraft maintain certification by federal regulatory agencies for commercial use after being used for evacuation missions requires that the aircraft floors not be overstressed.

The objective of this research is to provide 10 copies of hardware for a breadboard design to be used in a test program for the purpose of verifying the structural integrity of the stanchion system. The stanchions must be functional, structurally sound, capable of being installed on the existing seat tracks in a variety of aircraft and, under the design load conditions specified in MIL-STD-008865A (2), must not deliver aircraft floor loads which exceed the allowable floor loads for a particular aircraft. The last requirement is by far the most stringent and the one to which the greatest amount of effort has been directed during this project.

Because of the sensitivity of the floor loads to changes in geometry and the considerable differences between the various LRI aircraft of CRAF with regard to seat track geometry and the arrangement of hard points for making attachments, the actual detailed hardware fabricated is limited to that suitable for a Boeing 747. This aircraft was chosen since it was the prime choice designated by the contract monitor. Available data included the geometry of the seat track arrangement and the location of hard points and specific data on the allowable floor loads for the 747. While the breadboard design described here is specifically sized for the 747, the design could also be used on other CRAF with changes. A modification of the breadboard design could be made to include mechanical adjustment capabilities to allow the stanchion to be used interchangeably on other airplanes in CRAF. Allowable ultimate floor loads restricted the resulting design to litters stacked no more than 3 high. The requirement was due to the excessive floor loads caused by more patient weight and by moments induced on the structure and hence on the floor by the large lever arms which exist for the 4 litter case.

The transient dynamic load problem was not studied specifically in this research. However, further investigations such as those done in earlier studies (3-8) would be appropriate during the production design phase of the stanchion development program. Patient restraint problems would also be significant to consider in a later analysis.

Patient restraint methods provide little if any restraint in the longitudinal direction. This shortcoming is particularly important since the most significant dynamic loads are in the longitudinal direction.

THE BREADBOARD DESIGN

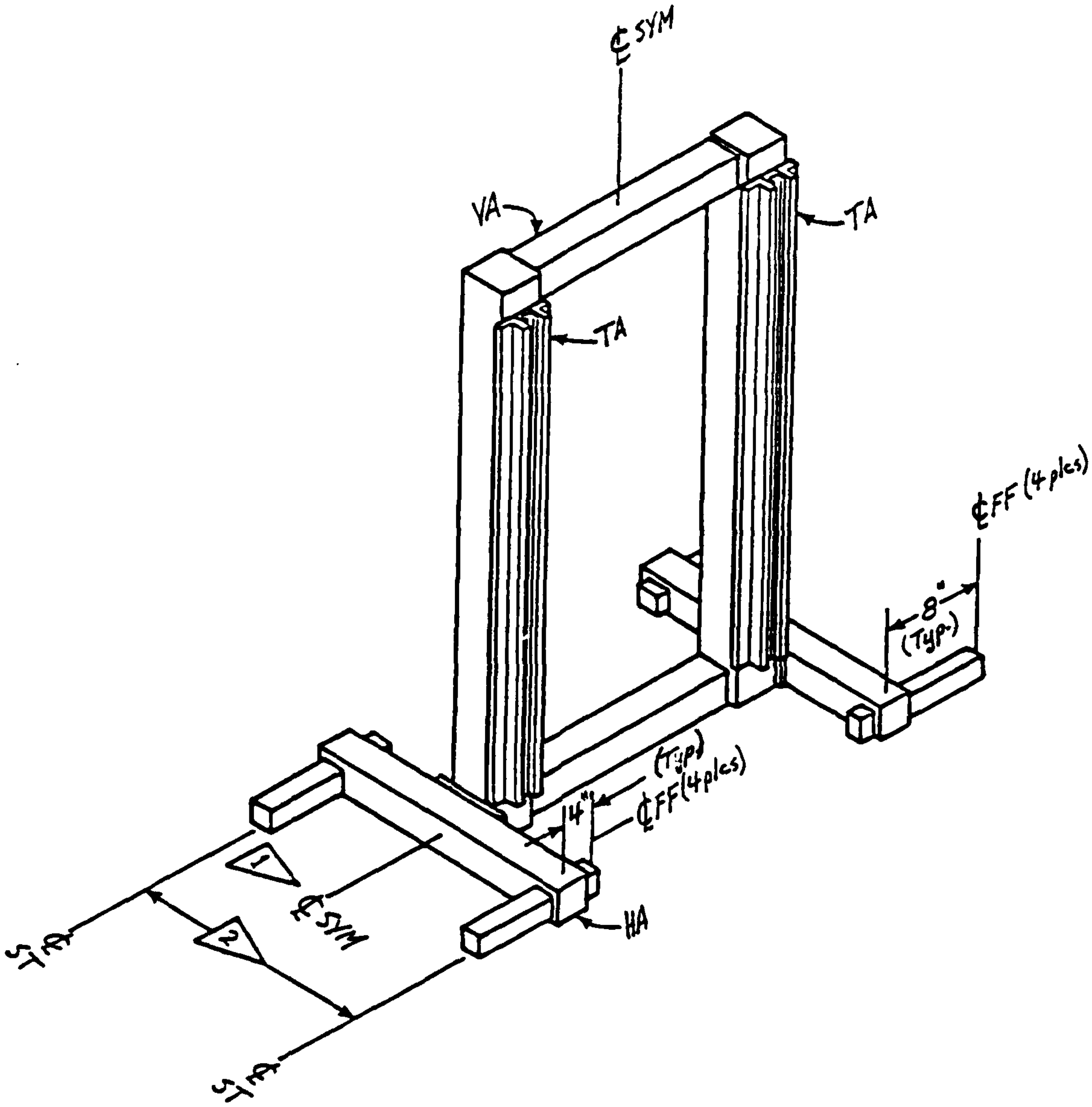
Background and Geometry

A major decision influencing the breadboard design is that since the C-9 arms have been successfully surviving actual in-flight loads for some time and seem to be a sound, lightweight, readily procurable item, the breadboard design should incorporate means of accepting them. This item is a close tolerance part made of high strength material, and development of a similar item exceeds the scope and available funds for this effort.

From our analyses (9 and this report) several other guidelines have dictated the way in which our breadboard design is arranged (Figs. 1-5). For instance, loading 4 parallel tracks with all the stanchion-pair loads originating near their centerline showed that the 2 most outboard tracks carried very little load. There are also aircraft dependent limitations which set upper limits to the EI (bending rigidity) values of members that are "attached to more than two tracks laterally..." (11). This limitation is not specified for all CRAF aircraft.

Early analysis indicated floor loads far too high for just 2 pickup points per stanchion (4 per stanchion pair). Therefore, to spread the load, 2 along-the-track pickup points separated by a convenient distance are used in place of each single pickup point. This arrangement is facilitated by the only rather "healthy" (strength-wise) track hold-down fitting known to be available (10). This fitting has a 5-cm (2 in.) wide U-shape <u>in line</u> with the track (Fig. 5) as opposed to a U-shape <u>perpendicular</u> to the track for stanchions presently used on the C-9 aircraft.

Aircraft requirements that limit both the <u>number</u> of loads/bay between floor beams, and/or <u>magnitude</u> of the loads for 2 loads/bay, also influence the dimensions of the breadboard design. The side-to-side floor beams on the 747, for instance, are 51 cm (20 in.) on center. To use the highest allowable loading arrangement, pickup points would have to be greater than 51 cm (20 in.) apart (<u>along</u> the track), but this has proven impractical to implement using 8 floor attachment points and the available floor fittings.



SYM = Symmetry
FF = Floor fitting
ST = Seat track
VA = Vertical assy
HA = Horizontal assy
TA = Track & angles for receiving litter support arms (max 3 arms)

1 Except TA's on one side only

2 To match Boeing 747 ST's, 22.66 in.

Figure 1. Stanchion pair breadboard design (floor fittings not shown).

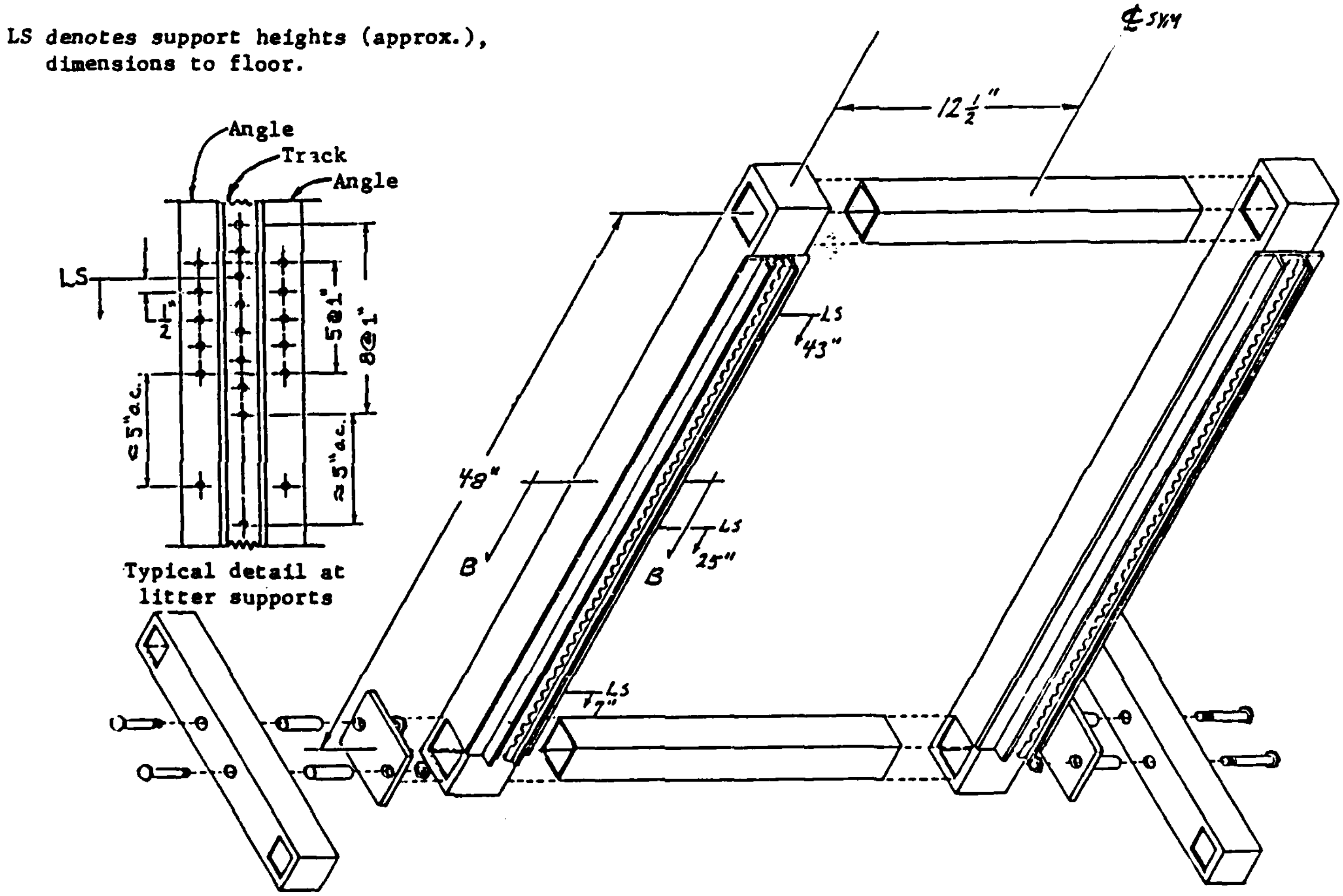
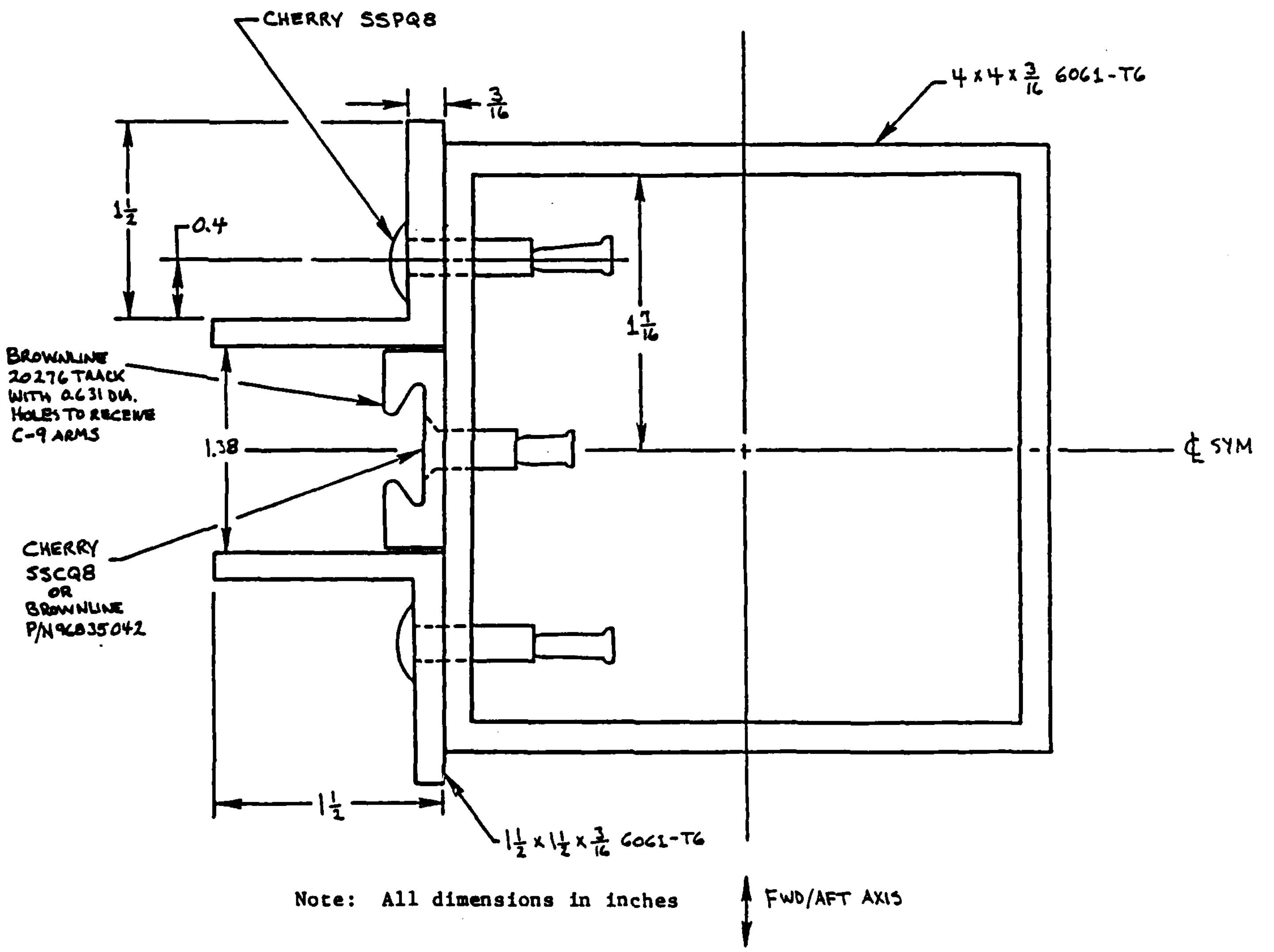
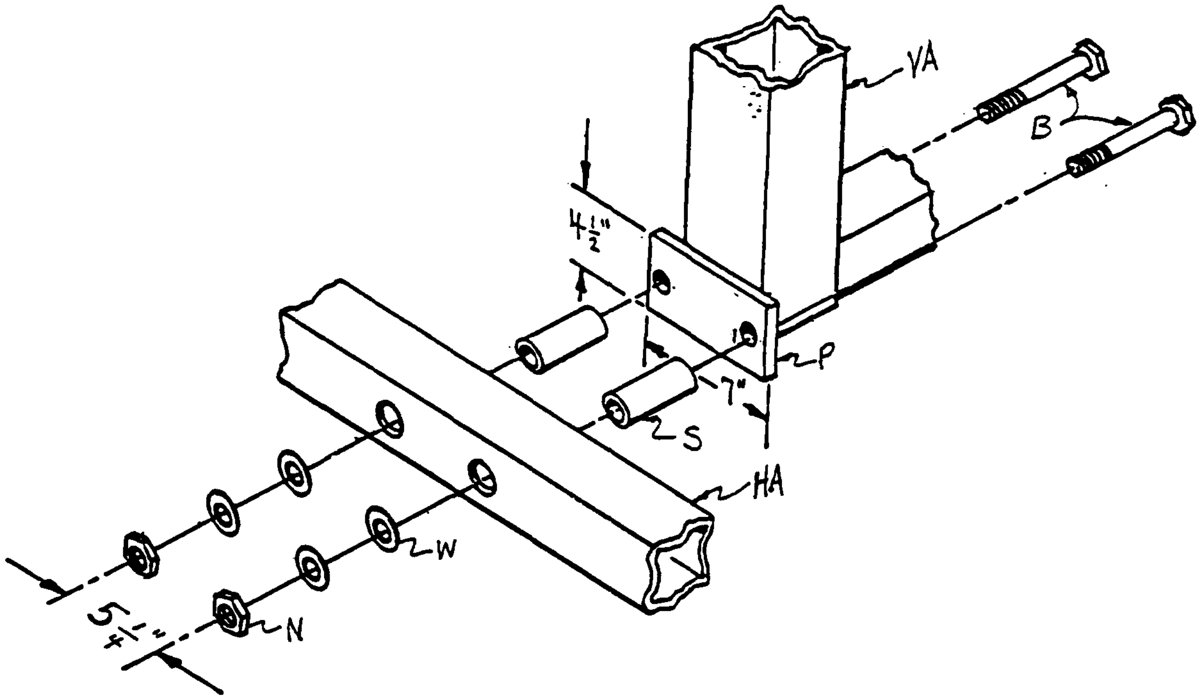


Figure 2. Exploded view of vertical assembly. (See Fig. 3 for Section B-B.)



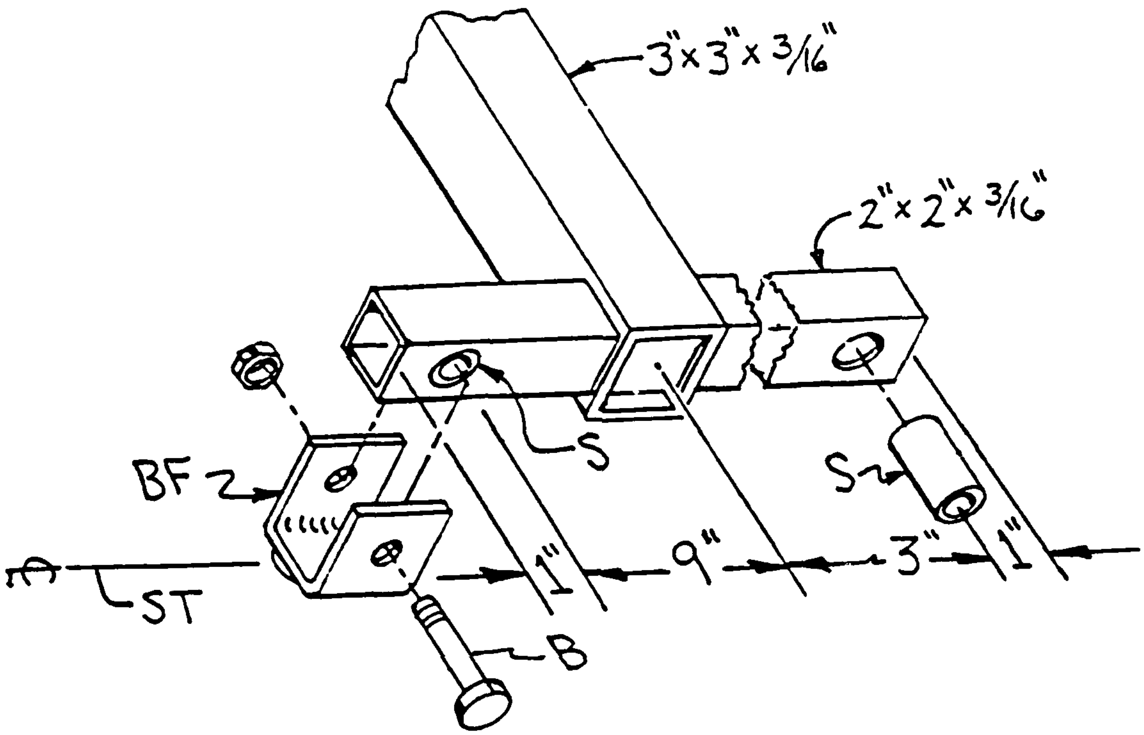
Note: All dimensions in inches

Figure 3. Section B-B through vertical member (Full Scale).



B = Bolt 1/2 in. x 3-1/2 in. grip
HA = Horizontal assy
N = Bolt nut
P = Connecting plate
S = Bolt sleeve
VA = Vertical assy
W = Washer

Figure 4. Exploded view of connection between horizontal assembly (HA) and vertical assembly (VA).



B = Bolt 3/8 in. x 2-1/2 in. grip
BF = Brownline floor fitting
S = Bolt sleeve
ST = Seat track

Figure 5. Exploded view of stanchion detail at and near each floor fitting.

Some seat tracks are "harder" than others. The BL33.99 seat tracks in the Boeing 747, for example, have considerably higher allowable loads (30% or more) than other tracks in the 747 floor. A summary of allowable ultimate Boeing 747 floor loads and a typical floor-load restriction curve are shown in Appendix A.

Litter heights were specified in the task assignment of the contract to be--bottom patient no less than 13 cm (5 in.) from the floor; and minimum spacing between litters will be at least 46 cm (18 in.). The analysis and Boeing 747 floor-load limitations from Reference 11 have dictated a "three litters on one side only" arrangement and prevented more elaborate arrangements.

Of the near infinite number of possible design choices for a stanchion pair, the process of arriving at one to build and test can be summarized as follows:

With multiple litter heights desired, vertical members at the litter support points seem obvious (as opposed to some sort of A-frame, for example).

The fore-and-aft position of these vertical members is a design variable. These vertical members could be rather close together like the as-built stanchion pair, or closer, or they could be far apart. If vertical members are far apart, there seems to be little advantage to use any other separation distance other than a standard litter length 203 cm (80 in.) as premium space would be wasted.

Considering 2 vertical members 203 cm (80 in.) apart, loads as members cantilevered from the floor are too high and a truss-like framing arrangement between them must be used. It is not feasible to have a 203-cm (80 in.) long rigid unit in terms of stow-away capability. A nonrigid arrangement requiring installation by unskilled labor with simple tools introduces severe unknowns into the design. Columns or cables or straps of lengths in the neighborhood of 2.5 m (8 ft) or so with installation tensions which cannot be guaranteed, and the use of "X'd" cables (one to resist forward loads and one aft loads) is not, in our opinion, good design practice. The use of the "X'd" cables introduces redundancies into the design, adding to those associated with unknown floor rigidities which already exist. Also, cable whip phenomena or possible column buckling in the case of structural failure of this arrangement could contribute greatly to patient injury.

Spacing the 2 vertical members close together has 2 advantages: (1) stow-away and installation features of a compact vertical frame are advantageous compared to the aforementioned cable-frame arrangement, and (2) "rigid frame" design yields a more efficient structure than one involving pins, redundant cables, and/or long columns.

Selection of just how far apart the 2 verticals should be is certainly a highly arguable point. The authors have used 63 cm (25 in.), a dimension that is compatible with all CRAF MED-E-VAC layouts. A longer distance between the 2 verticals has two disadvantages: (1) litter stanchion pair weight is increased, and (2) the number of in-line litters on the aircraft may be reduced. While not required, it is thought that nurse access between the vertical members may become highly desirable in the implementation of the system.

Before arriving at the final configuration, numerous other geometries were analyzed. The original floor attachment geometry had 4 floor attachment points on one side of the vertical members (1). Analysis of this configuration revealed that the floor attachment points farthest from the vertical member only carried about 10% of the total load transmitted to the floor. To more evenly distribute the load, the attachment points were arranged so that there were 2 attachment points on each side of the vertical members. This configuration better distributed the load between 4 floor attachment points, but under certain loading conditions the floor loads were still excessive. To reduce the loading at the attachment points to acceptable values, the number of attachment points was increased by the inclusion of 4 small beams running parallel to the seat tracks and placing the floor attachment points at the ends of these beams. The previously described floor attachment configuration is basically the same as the final floor attachment configuration except in the final configuration the floor fitting locations and the size of the small beams are optimized.

Design Features

The use of a rectangular frame made of square tubes for the vertical litter support frame provides a structural arrangement that is adaptable for various litter heights and which has both good torsional and bending characteristics. Square tubes, while not the most efficient section for resisting high bending loads alone, are most desirable for the situation of stanchions subjected to loads in 4 different directions. These loads lead to bending about 2 different axes, torsion, possible critical column loads, etc.

The 2 horizontal assembly frames (Fig. 1), of shorter spans and involving smaller tubing, spread the loads to seat track pickup points.

At each end of the vertical frame, plate and bolt arrangements are used to attach the vertical frame to the 2 horizontal frames. This arrangement provides for better storage/shipping geometry and allows the vertical frame to be placed closer to the floor to keep the litters as low as possible. This connection also eliminates a very unfeasible installation requirement of trying to attach 8 tie-down points at once.

For the tie-down arrangement, off-the-shelf hold-down brackets were modified to use 1 bolt at each connection to the horizontal track tie-down frame. This arrangement provides a pin connection and therefore some leeway in the dimensional tolerance along the track between the hold-down fittings. Floor expansion joints, however, could be a problem. (Such interruptions in the 2.54-cm (1 in.) stud-to-stud dimensions are no problem if they occur between the stanchion pairs.) We expect that installation of the separate horizontal frame assemblies will require 2 individuals; more than 2 hands are required to get all 4 support fittings of 1 horizontal frame in place, and at least 1 person would have to hold the vertical frame while a second person attaches it to the 2 horizontal frames.

A number of alternative dimensional arrangements of the support fitting locations were considered. Extensive iterations of the analysis along with considerations of availability of suitable structural members led to the arrangement shown (Fig. 1). The reason for the 20-cm (8 in.) and 10-cm (4 in.) offsets of the support fittings on the horizontal assembly is to decrease the severity of the loads in the dominating -9 G case. The vertical loads applied to the seat tracks are excessive for this case with 15-cm (6 in.) symmetrical spacing (i.e., 20 cm (12 in.) between fittings) and for 56-cm (22 in.) spacing. Table 2, to be discussed later, further addresses this matter. Reducing these vertical loads to those within the maximum allowed (11) has been the driving force in the breadboard design iterations.

An actual photograph of one of the as-built stanchion pairs is shown in Figure 6(A). Only the second highest litter arms are attached. Due to the camera's downward angle, there is some distortion that makes the lower parts of the stanchion pair seem smaller than they really are. Also shown is a welding jig in Figure 6(B) that was used for stanchion pair fabrication. The jig was made from actual track, and the floor fittings shown were actually held in place for welding of the stanchion. (Only 6 of the 8 floor fittings are shown--the other 2 are just out of camera view to the top of the photograph.)

LITTER STANCHION STRUCTURAL ANALYSIS

The litter stanchion design requires an analysis to evaluate the structural integrity of the stanchion and to determine the loads transmitted to the CRAF aircraft. The structural integrity of the stanchion is determined from the ultimate strengths of the materials used. The floor loads are determined from the reaction forces generated at the points where the stanchion is attached to the aircraft floor. The allowable floor loads for the Boeing 747 are defined by Boeing document No. D6-13427 (11). The required equivalent static loading conditions which are used in the structural analysis are obtained from MIL-STD-008865A (2) and the Task Description.

The structural analysis was done using the finite element method and the MSC/NASTRAN general purpose finite element computer code. Beam elements with up to 6 degrees of freedom at each end are used to model the stanchion as a three-dimensional frame. Although the real loads applied to the stanchion will be of a dynamic nature, only static analyses are documented here, consistent with the load factors referenced in MIL-STD-008865A (i.e., equivalent static loads which include a built-in dynamic load factor).

The most difficult part of the modeling was the determination of the appropriate constraint conditions to apply at the interface points between the stanchions and the aircraft floor. Several possibilities were considered for approximating the connection between the stanchion studs and the slotted floor track support. The first possibility consisted of assuming that a rigid or clamped condition existed at the attachment points. However, because of the lack of actual fixed constraints against bending moments and torques, this assumption was not very accurate. This method, however, provided an upper bound for the floor loads. The second assumption considered the attachment point to behave as a ball joint (i.e., only translational degrees of freedom were restrained and therefore no bending moments or torques were transmitted to the floor). This method was a somewhat better assumption but still did not

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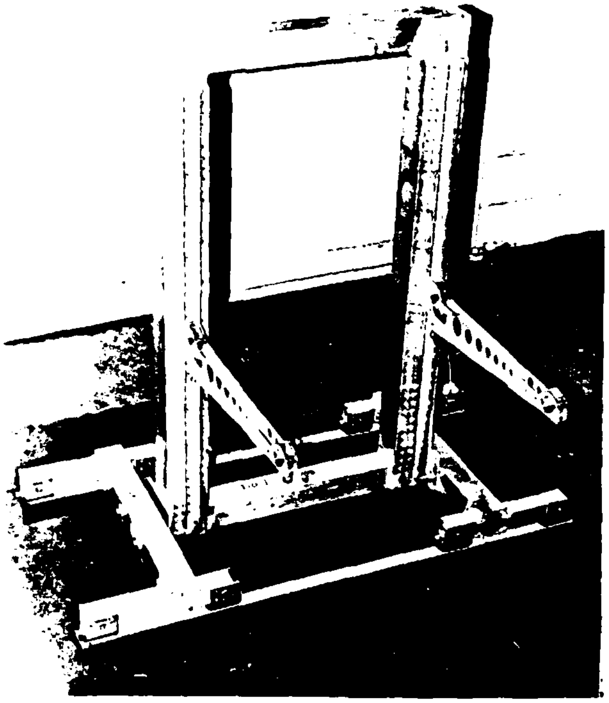

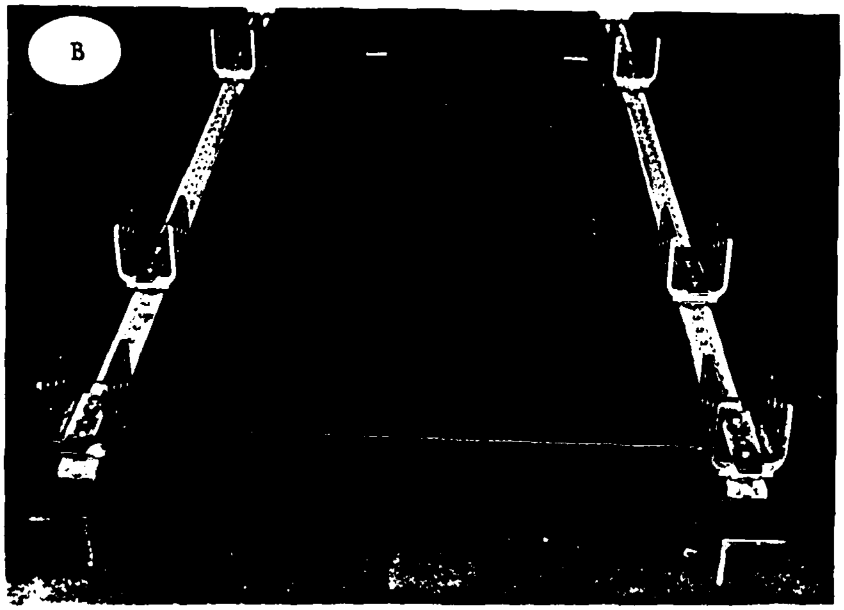

Figure 6. As-built stanchion pair (A) and welding jig (B).

account for any loose fit between the stanchion and the floor, or for the elasticity of the floor, or floor fitting. The modeling of the loose fit would require an iterative and/or nonlinear analysis to be performed, an analysis which was not done because of cost and time considerations. The elasticity of the floor and fitting was finally modeled by using linear springs in each of the three possible translation directions, the spring being connected between the stanchion attachment points and an assumed rigid floor. This model provides a more reasonable assessment of the floor loads. The major uncertainty with this assumption is the magnitude of the spring constants. However, the analysis shows that the magnitude of the floor loads is not strongly dependent on the spring constants used. Table 1 is evidence of this analysis (3 litter, -9 G load factor, longitudinal case).

Typical Results

Grid Arrangement

To discuss typical results, refer to Figure 7 and the grid numbering scheme shown in the NASTRAN-generated isometric view of our most thoroughly investigated stanchion pair analytical model with 16 C-9 litter support arms (the 8 litter case).

Constraint Loads

Since our task assignment included the necessity not to overload the seat tracks in existing aircraft, much attention has been given to the constraint forces (constraints at grid points 2, 3, 19, 20, 56, 57, 60, and 61; Fig. 8). These forces are readily available from NASTRAN; however, some judgment as to their realistic values must be made as such values are very dependent on the assumptions of the constraints. Our analyses have centered on 2 constraint arrangements: (1) each constraint grid point is prevented from translating at all in any of the 3 directions (referred to as a "rigid" constraint), and (2) each constraining grid point can move against elastic springs. The springs simulate the nonrigid, but reasonably stiff, aircraft floor structure to which the seat tracks are attached. (The fitting itself provides some of this flexibility as well.) The differences in constraint forces are quite significant. For example, consider the constraint forces tabulated in Table 2. Note the significant difference especially in the longitudinal constraint forces for the -9 G case. The only differences in the computer runs here are the rigid vs. elastic constraints. A comparison of these loads with the allowable loads of Boeing Document No. D6-13427 (11) clearly indicates that a maximum of 3 litters (on one side) with elastic constraints is, in the authors' opinion, the only reasonable case to consider for the final breadboard design. Table 3, to be discussed later, supports our conclusion.

Several other support-fitting separation distances different from the final arrangement were thoroughly investigated. Similar trends in constraint load patterns were present.

Final Analysis Model and Results

A sketch of the analysis model of the as-built stanchion pair is shown in Figure 8. Both grid numbers and beam element numbers are indicated on the figure. Some of the pertinent cross-sectional computations are given in

TABLE 1. CONSTRAINT FORCE COMPARISON FOR DIFFERENT SPRING STIFFNESSES: -9 G LONGITUDINAL LOADING

Grid Point*	k = 500 lb/in.	k = 1000 lb/in.	k = 2000 lb/in.
	Vertical Constraint Forces		
2	1760.1	1717.1	1691.9
3	655.0	580.7	507.3
19	-655.0	-580.7	-507.3
20	-1760.1	-1717.1	-1691.9
38	2032.8	2052.4	2048.1
39	1079.2	1207.7	1349.4
41	-1079.2	-1207.7	-1349.4
42	-2032.8	-2052.4	-2048.1
	Lateral Constraint Forces		
2	358.3	202.0	-2.5
3	344.6	410.0	492.5
19	-344.6	-410.0	-492.5
20	-358.3	-202.0	2.5
38	734.8	819.1	907.0
39	283.2	321.7	394.3
41	-283.2	-321.7	-394.3
42	-734.8	-819.1	-907.0
	Longitudinal Constraint Forces		
2	1334.0	1362.7	1416.8
3	1298.7	1295.2	1287.5
19	1298.7	1295.2	1287.5
20	1334.0	1362.7	1416.8
38	668.0	679.2	703.3
39	621.9	585.4	515.0
41	621.9	585.4	515.0
42	668.0	679.2	703.3

*Grid points are consistent with those shown in Figure 8.

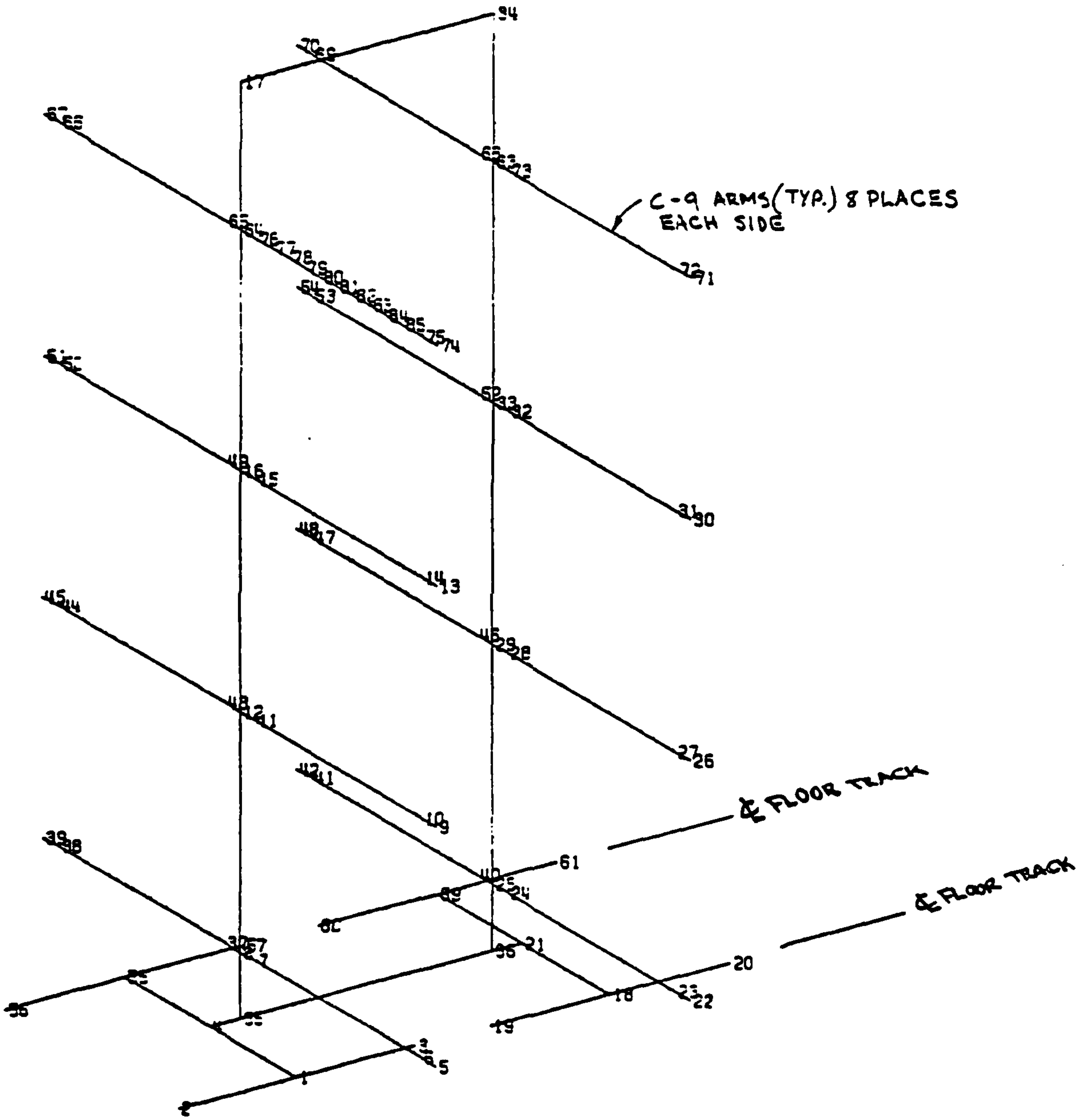

Figure 7. Preliminary NASTRAN-generated static analysis model.

N = Grid numbers

(N) = Beam element nos.

N = Constraint grids

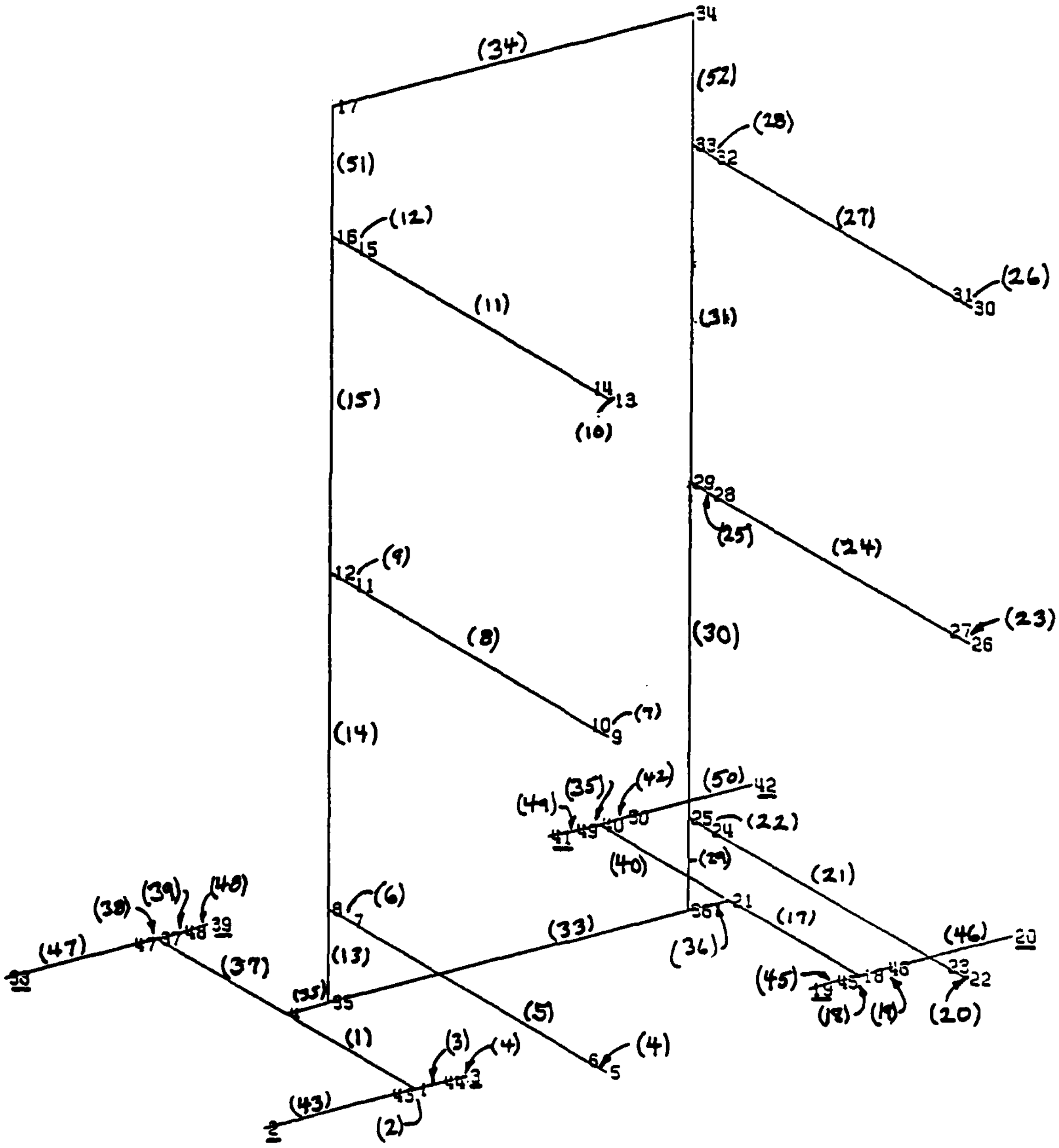

Figure 8. Final NASTRAN-generated static analysis model (3-D elastic springs at each constraint omitted).

TABLE 2. CONSTRAINT FORCES FOR -9 G LOAD

Grid point	Vertical Constraint Forces (lbs)							
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
2	5276	5754	3320	3274	3320	2827	2300	1399
3	4370	3323	2099	1767	1788	1329	1077	1335
19	-4368	-3323	-2099	-1767	-1789	-1329	-1078	1334
20	-5275	-5754	-3319	3274	3319	-2827	-2300	1398
56	5276	5755	3455	3275	3470	3205	2320	738
57	4372	3324	1259	1768	3871	2156	2345	656
60	-4372	-3324	-1259	-1769	-3871	-2156	-2345	657
61	-5276	-5755	-3455	-3275	-3470	-3205	-2320	738

Case 1: 8 Litter rigid model

Case 2: 8 Litter elastic model

Case 3: 6 Litter rigid model

Case 4: 6 Litter elastic model

Case 5: 4 Litter rigid model

Case 6: 4 Litter elastic model

Case 7: 3 Litter rigid model

Case 8: 3 Litter elastic model

TABLE 2. (Continued)

Grid point	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Vertical Constraint Forces (lbs)								
2	14053	2651	8870	1997	9013	1831	6336	1399
3	-8995	2407	-4944	1864	-4207	1718	-2490	1335
19	-8995	2406	-4944	1863	-4208	1717	-2490	1334
20	14052	2651	8868	1997	9012	1830	6334	1398
56	14052	2650	10429	1996	9091	959	6104	738
57	-9001	2405	-6620	1862	-7362	817	-4613	656
60	-8999	2406	-6620	1863	-7361	817	-4611	657
61	14055	2650	10430	1996	9091	960	6105	738
Lateral Constraint Forces (lbs)								
2	-2758	-875	-1382	-620	-1790	174	1281	142
3	-3556	-49	204	32	-1129	471	-257	385
19	3556	49	-204	-32	1129	-471	258	-385
20	2758	875	1382	620	1789	-474	1287	-141
56	2758	876	1142	622	1756	1091	1252	804
57	3559	50	-217	-31	3502	523	2008	357
60	-3559	-50	217	30	-3501	-523	-2008	-357
61	-2758	876	-1142	-622	-1756	-1091	-1252	-804

Appendix B. G-load factors of ±1.5 G side, 9 G forward, 4.5 G down, and 2 G up were used. Due to certain axes of symmetry, these factors represent a thorough check on the various loading conditions.

Non-NASTRAN Analysis

There are many analysis considerations in an effort such as this, but in this day of sophisticated finite element analysis software such as NASTRAN, many such considerations are hardly worth documenting extensively. Interestingly, however, a "by-hand" analysis did lead the way to the more realistic (in our opinion) constraint conditions discussed elsewhere. This analysis served as a good check on the NASTRAN model. For instance, Table 3 reveals good agreement between an elementary analysis and a complete NASTRAN model.

TABLE 3. COMPARISON OF SIMPLE ANALYSIS WITH NASTRAN ELASTIC ANALYSIS

	8 litters (4/side)	6 litters (3/side)
Highest vertical floor load	10214/7600*	5506/4315
Lowest vertical floor load	2042/2142	1101/1097
Shear load at floor	2394/2433 to 2623	1796/1877 to 1982

*Simple analysis/NASTRAN analysis with elastic constraints (throughout table). All loads in lbs.

More importantly, NASTRAN does not perform a number of calculations. The stress checks that we performed are summarized in Table 4.

TABLE 4. NON-NASTRAN STRESS CHECKS

Part	Condition description	Max load	Max load (lbs)	Max stress (psi)
1 cm (1/2 in.) diameter bolt	Combined tension and single shear	9 G Case	5558(s) 3846(t)	49539
1 cm (3/8 in.) diameter bolt	Double shear	9 G Case	1291	11691
Floor fitting	Bearing at bolt shear tearout maximum section tension	9 G Case	2052	21892
10 cm x 10 cm beam-column (4 in. x 4 in.)	Buckling	9 G Case	2998	-11265

PRODUCTION DESIGN CONSIDERATIONS

The major considerations in a production design are at least twofold. First, should certain CRAF models be excluded from use due to the unfeasibility of having stanchion pair that can fit in all aircraft of interest? Our recommendation would be to exclude the -10 through -50 models of the DC8 since on each side of the centerline, seats are supported by a wall track (in the fuselage wall, not in the floor) and a floor track. One could use jointly the 2 floor tracks on each side of the aircraft centerline, but the separation distance is 127 cm (50 1/8 in.); quite different from other CRAF aircraft. DC8-60 models and other models of interest are probably comparable enough to all be used in the present scheme.

Secondly, a stanchion pair to fit as desired in the multiplicity of CRAF aircraft would need a butt-line adjustment to fit track-to-track centerline dimensions of 48 cm (19 in.), 50 cm (20 in.), 52 cm (20.75 in.), 57 cm (22.6 in.), and 81 cm (32 in.). "Telescoping" of the track-to-track connecting member of the horizontal frame of the breadboard design has possibilities, but trade-offs with production limitations will most likely dictate the approach taken. The breadboard as-built stanchions do not have this feature. It is possible that 4 dimensions (of the 5) might be incorporated into the production design with some means for handling the 48-cm (19 in.), 50-cm (20 in.), 52-cm (20.75 in.), and 57-cm (22.6 in.) cases with a single, unaltered stanchion-to-floor fitting arrangement. This feature would place three-dimensional loads on the floor track, however, whereas most of the aircraft load data available deals with two-dimensional loads (up and axial or up and side, etc.). This feature could also dictate the development of a new floor fitting that is beyond the scope of the present effort.

Alternatively, a double stud fitting may be available or a new design made so that the U-shape of the fitting would be perpendicular to the Brownline fitting used in the breadboard design (Fig. 5). Then, by sliding the fitting to different butt-line positions and using quick release pins, the various track-to-track dimensions could be handled. This design would require a different arrangement of the horizontal frame than the present breadboard design. Such an alternative opens up "Pandora's Box" again concerning number of floor support points, floor rigidity, etc.

One appropriate telescoping design is shown in Figure 9. This design would be a modification to the present breadboard stanchion horizontal assemblies (HA in Fig. 1). The 2 bolts shown in the slots are the bolts which attach the horizontal assemblies to the vertical assemblies (B in Figure 4). An 8-cm (3 in.) slot and the use of telescoping square tubes would provide for adjustment to fit the 48-cm (19 in.), 50-cm (20 in.), 52-cm (20.75 in.), and 57-cm (22.6 in.) cases described previously. The design will not work for the 81-cm (32 in.) case due to the dimensions involved (i.e., the largest tube's length is limited by the narrowest track-to-track centerline; there is insufficient room for the slotted tube to meet both extremes).

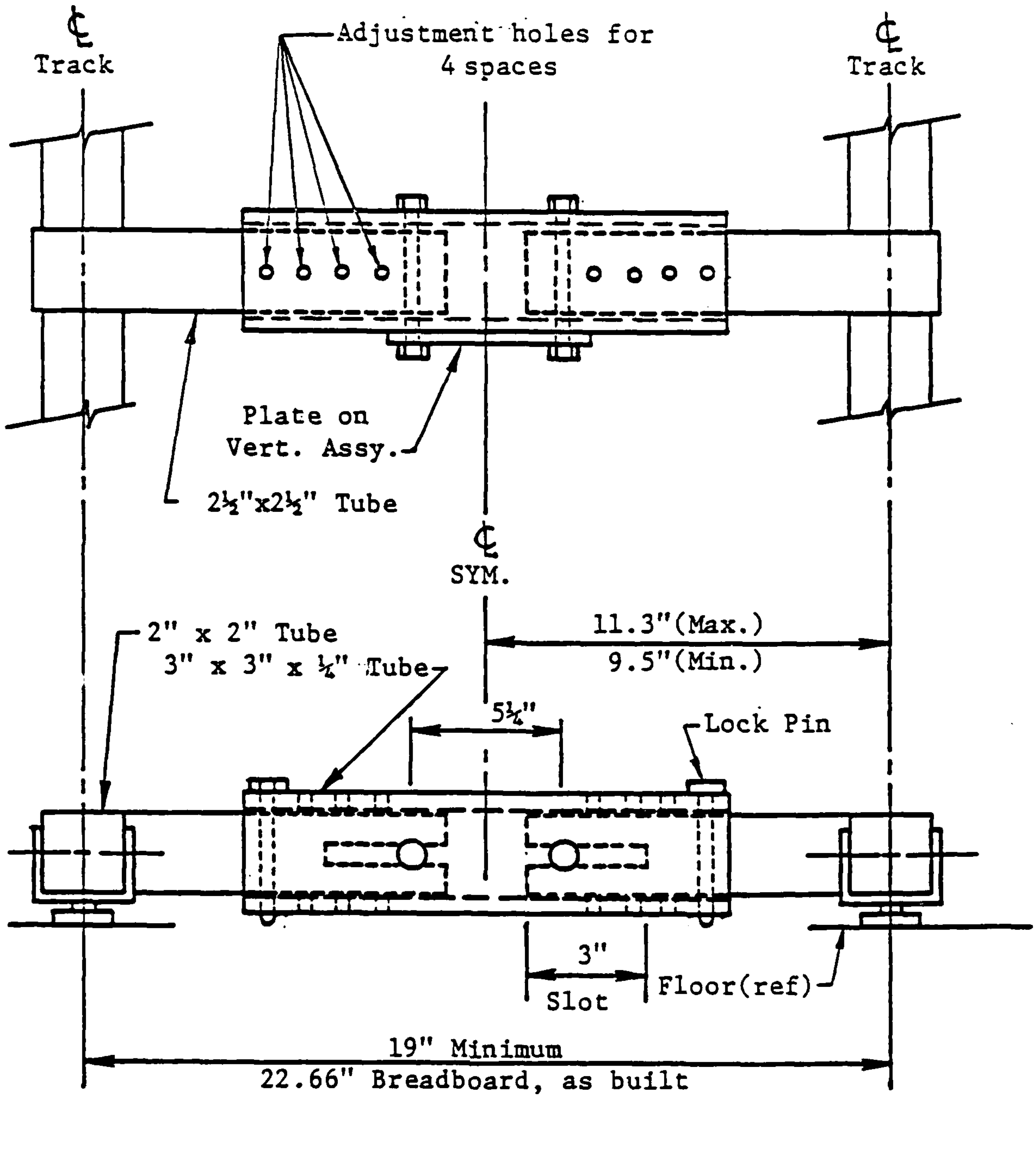

Figure 9. Simplest telescoping design of the horizontal frame assembly.

Other production design considerations include, but are not limited to the following:

- Costs; see Appendix C for a rough approximation.
- Are floor track splices significant enough to deal with from loads and from installation restriction standpoints?
- Do the floor tracks with electric service in the DC10 interfere with the litter stanchion concept? Or vice versa?
- Which of the multiplicity of G-load factors used by the different manufacturers dictates the minimum weight stanchion design (as opposed to going just by the MIL-spec or a contract task assignment)?
- What technique is most desirable for production litter stanchion construction? Fabrication used for the breadboard model may not be consistent with the most feasible production design methods.
- Would some combination of single stud floor track fittings and double stud fittings work better for the production design?
- Would it be best to use an off-the-shelf floor fitting as the breadboard design has done, or develop a new floor fitting?
- Would it be best to use the available C-9 litter support arm (as the breadboard design does), or could some sort of snap-in-place arm be incorporated into the production design? Storage improvement and quick-installation features could certainly be improved by such an arrangement.

AIRCRAFT COMPARISON

The major differences in the CRAF aircraft that are of interest here are the variations in track-to-track dimensions in the butt-line direction (previously discussed), and in the various floor-load limitations. Since nearly all of this information is proprietary (13,14,15), it is shown in Table 5 identified only as aircraft A, aircraft B, etc.

TABLE 5. AIRCRAFT COMPARISON

Aircraft	Basic track-to-track dimensions (inches)	Floor beam ℄ to ℄ (inches)	Floor load allowable
A	22.6	20	See Appendix A
B	20.75	Unknown	Proprietary
C	19 (near ℄) 19 (near windows)	Unknown	Proprietary
D	20	Unknown*	Proprietary

*16 inches required between floor fittings.

It is possible that a restriction of the number of models in which stanchion pairs may be used could result in an arrangement of fewer floor attachment points due to higher allowable floor loads for certain aircraft.

PERTINENT FAA AND OTHER REGULATIONS

The primary importance to this effort is the Boeing requirement (11, p. 53) that tests of structures (furniture) to be subjected eventually to flight conditions must be accomplished with simulated aircraft floor support structure. While this requirement refers to flight hardware, our NASTRAN analysis has shown the critical nature of such support conditions, and the authors strongly agree with this Boeing requirement. To test the structure on a "rigid" test frame is probably meaningless.

Federal Aviation Administration (FAA) regulations of interest are summarized in Code of Federal Regulations (12). Many of these regulations are consistent with the Task Directive of this effort. Two regulations stand out as exceptions: (1) the contrast in patient weights 77.11 kg (170 lbs) FAA, 113.4 kg (250 lbs) USAF, and (2) the requirement that:

> "Each berth installed parallel to the longitudinal axis of an airplane must be designed so that the forward part has a padded end-board, canvas diaphragm, or equivalent means that can withstand the static load reaction of the occupant when the occupant is subjected to the forward inertia forces prescribed..."

The latter may be a very key element in eventual success of protection of the patients and could also affect the assumed loading arrangement.

Dynamic tests rather than static tests could also significantly affect results. A new FAA regulation on dynamic tests (§ 562) is scheduled to be published in the fall of 1985. An example of the significance of dynamics is: in a near-ultimate load situation (e.g., -9 G's or 4.5 G's) when deflections are large and probably nonlinear, is the assumption of one-fourth of the patient's mass acting at each litter support appropriate? Or does the inboard (less deflected) litter support take on a greater percentage of the mass? Static tests will not answer this question.

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APPENDIX A

SUMMARY OF ALLOWABLE ULTIMATE BOEING 747 FLOOR LOADS

Figure A-1 is a typical allowable curve for load combinations (11). Double stud values apply. The length s is 18 cm (12 in), while x could be any value less than 15 cm (10 in). Figure A-2 is a summary sketch gathered from typical curves like Figure A-1 from Document No. D6-13427 (11).

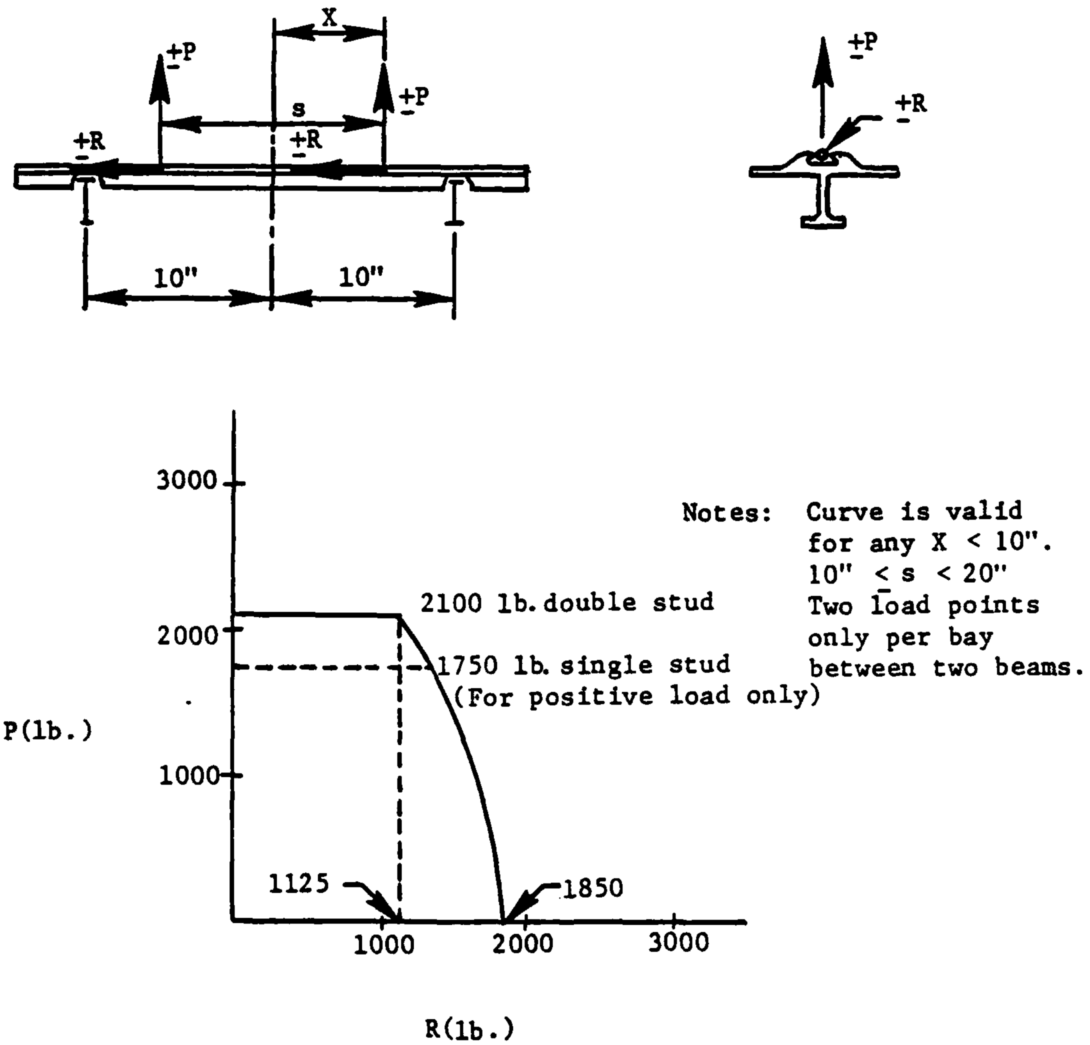
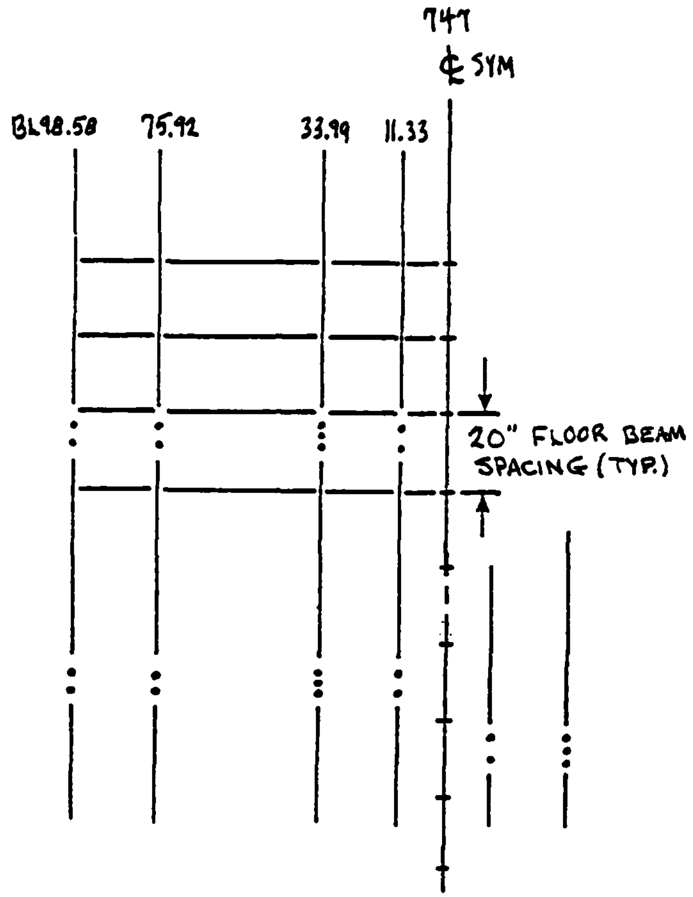


Figure A-1. Allowable vertical and axial load combinations, BL 67 and 89.67 seat tracks (from Reference 11).



All loads are maximum vertical load in pounds; for double stud and axial force in line with track.

——··——Hard seat tracks	4810*	(one load between beams) with 3700 axial*
——··——Soft seat tracks	3600*	forward of sta. 2110 (one load between beams) with 3700 axial*
	2900*	aft of sta. 2110 (2100* if two loads 10 or more inches apart between beams) (one load/bay)
	2900	with 2250 axial* aft of sta. 2110 $s \geq 20$
	2100	with 1125 axial* aft of sta. 2110 $10 \leq s \leq 20$ (2 loads/bay)

*reduce if vertical with side load

Figure A-2. Summary of Boeing 747 floor load limits (11).

APPENDIX B

CROSS-SECTION COMPUTATIONS*

The properties of most of the cross sections used are simply square walled tubes. Their properties are found using Figure B-1:

	5.1 cm (2 in.)	7.6 cm (3 in.)	10.2 cm (4 in.)	
$A = s^2 - (s-2t)^2$	8.768 (1.359)	13.606 (2.109)	18.445 (2.859)	cm^2 $in.^2$

For either bending axis:

$I_{zz} = I_{yy} = 1/12\ s\ s^3 - 1/12\ (s-2t)(s-2t)^3$	31.301 (0.752)	116.253 (2.793)	289.031 (6.944)	cm^4 $in.^4$
$I_{yz} = 0.0$ due to symmetry	0.0	0.0	0.0	
$J_A = \frac{2t^2(s-t)^4}{2st-2t^2}$	46.4681 (1.1164)	173.6268 (4.1714)	432.4811 (10.3904)	cm^4 in^4

where the latter is the torsional constant found in "Formulas for Stress and Strain" (18).

The information shown in Figure B-2 for the 4 cm x 4 cm x 0.6 cm (1 1/2 in. x 1 1/2 in. x 3/16 in.) angles is taken from Alcoa Structural Handbook (17) in which only English units are used.

Computations for the two 10 cm x 10 cm x 0.6 cm (4 in. x 4 in. x 3/16 in.) main vertical members are more involved due to the track and angle arrangement to receive the C-9 arms. (The "track" is ignored in these calculations due to localized arm loads. Also the angles are ignored in the J_A computation.) By referring to Figures B-1 and B-3, it can be seen that:

*All notations used in this appendix agree with Schaeffer's analysis (16).

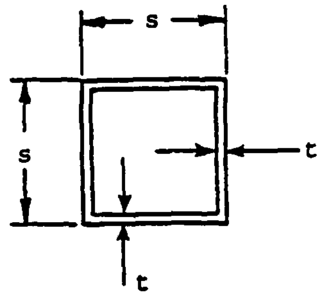


Figure B-1. Cross section through square tubes.

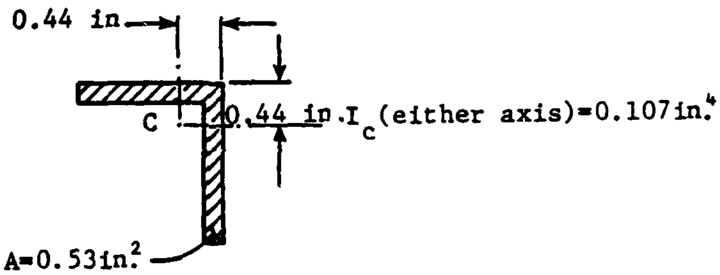


Figure B-2. Cross section and table properties.

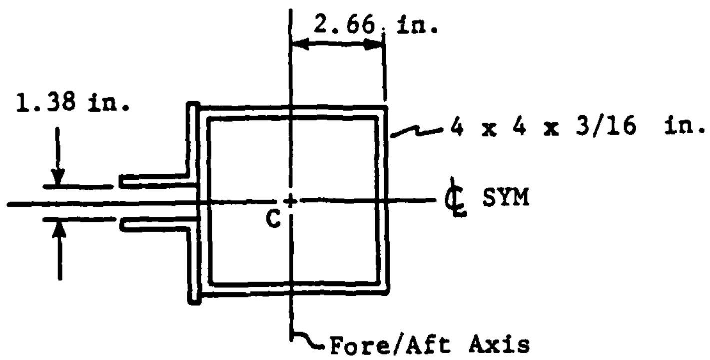


Figure B-3. Cross section through vertical litter arm support members.

$$A = 2.859 + 2\ (0.53) = 3.919\ \text{in.}^2$$

$$I_{\text{sym axis}} = 6.944 + 2[0.107 + 0.53\ (\frac{1.38}{2} + 0.44)^2] = 8.507\ \text{in.}^4$$

$$I_{\text{fore/aft axis}} = 6.944 + 2.859\ (0.66)^2 + 2\ [0.107 + 0.53\ (4-2.66+0.44)^2]$$

$$= 11.759\ \text{in.}^4$$

The respective values for the above in metric units are:

$A = 25.284\ \text{cm}^2$

$I_{\text{sym axis}} = 354.088\ \text{cm}^4$

$U_{\text{fore/aft axis}} = 489.447\ \text{cm}^4$

APPENDIX C

COST CONSIDERATIONS

The authors do not propose to have much expertise in making an estimate of a production run stanchion pair; there are too many unknowns. This breadboard effort is probably not a good measure of future costs due to our small machine shop effort, but highly skilled machinist, and special cooperation on parts procured from Brownline. A very rough approximation (per stanchion pair without litter support arms) and without overhead, profit, etc., is:

Tubing	\$190
Tracks and Angles (for litter support arm)	150
Floor Fittings	300+
Misc. (bolts, sleeves, rivets, etc.)	30
Subtotal	\$670
Labor	30 h

END

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